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A Comparison Between Phosphors for Aviator's Night Vision Imaging System (Reprint)

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Aircrew Health and Performance Division

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The visual display on night vision goggles (NVGs) is green and isochromatic (P22 phosphor). Future systems are expected to use a P43 phosphor which has a narrower visible spectrum and is yellowish-green, while the P22 is deeper green. In transitioning to the P43, some NVGs may have P22 and P43 phosphors paired in the same NVG. The purpose of this study was to evaluate the suitability of the P43 phosphor and the effect of mixing phosphors in the same NVG. We tested three systems: one with P22 phosphors in both tubes (P22), one with P43 in both tubes (P43), and one with P22 in the right and P43 in the left tube (mixed). Visual acuity (VA), contrast sensitivity (CS), flicker sensitivity, and dynamic CS were measured in six subjects with measures repeated across the three systems (P22, P43 and mixed). There was no difference between systems in VA or CS across a range of simulated night sky conditions. There also was no difference between systems in sensitivity to flicker. Performance on dynamic CS was slightly better with the P43 display, which may relate to the faster decay time of this phosphor. These results provide no contraindication for using the P43 phosphor in NVGs (paired or unpaired), but it would be prudent to minimize mixing of phosphors in the same NVG.

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A Comparison Between Phosphors for Aviator's Night Vision Imaging System

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Background: The visual display on night vision goggles (NVG's) is green and isochromatic (P22 phosphor). Future systems are expected to use a P43 phosphor which has a narrower visible spectrum and is yellowish green, while the P22 is deeper green. In transitioning to the P43, some NVG's may have P22 and P43 phosphors paired in the same NVG. The purpose of this study was to evaluate the suitability of the P43 phosphor and the effect of mixing phosphors in the same NVG. ***Methods:*** We tested three systems: one with P22 phosphors in both tubes (P22), one with P43 in both tubes (P43), and one with P22 in the right and P43 in the left tube (mixed). Visual acuity (VA), contrast sensitivity (CS), flicker sensitivity, and dynamic CS were measured in six subjects with measures repeated across the three systems (P22, P43 and mixed). ***Results:*** There was no difference between systems in VA or CS across a range of simulated night sky conditions. There also was no difference between systems in sensitivity to flicker. Performance on dynamic CS was slightly better with the P43 display, which may relate to the faster decay time of this phosphor. ***Conclusions:*** These results provide no contraindication for using the P43 phosphor in NVG's (paired or unpaired), but it would be prudent to minimize mixing of phosphors in the same NVG. Additional factors that may affect performance with different color displays are discussed.

NIGHT VISION GOGGLES (NVG's) amplify ambient light, making it possible to see and function in night environments. NVG's are used for military aviation and ground operations, search and rescue, law enforcement, and as visual aids for night blindness (3,5,20,21,23). **Fig. 1** shows the basic components of an NVG, which include infrared sensitive photocathode, intensification element (microchannel plate), and visual display. Focusable optical elements located at the front (objective) and back (eyepiece) of the NVG also form an important part of this system.

Efforts are underway to develop higher performance NVG's. While current systems (e.g., Aviator's Night Vision Imaging System; ANVIS) use P20 or P22 (green) phosphor visual displays, it is anticipated that future systems will use a P43 phosphor that has a narrower visible spectrum and peaks at a longer wavelength (545 nm; yellow-green) than the P22 or P20 phosphors (530 nm peak; deeper green). The narrow spectrum P43 produces less color aberration and thus may require fewer optical elements resulting in a more lightweight NVG. It also is more compatible with emerging lens technologies which require narrow band light (Bender E.J., Memorandum for Project Manager, Night Vision and Electro-Optics, Fort Belvoir, VA. 1994). Currently a P43 phosphor display is used successfully with the forward-looking infrared system on the Apache helicopter (17).

While the P43 phosphor may prove to be an asset for NVG's, it is important to consider the implications of using a different color visual display. Because ANVIS displays are isochromatic with no variation in color, visual performance should be comparable with P22 and P43 displays if they are matched in luminance and contrast (10). However, this assumption should be verified empirically, and other factors, such as adaptational state (11), chromatic aberration of the eye and spectral bandwidth of the stimulus (2,4,8) may influence visual performance. Moreover, in transitioning to the P43, some NVG's may be fielded with P43 and P22 phosphors paired in the same goggle. The purpose of this study was to evaluate the suitability of the P43 phosphor and the effect of combining different phosphors in the same NVG.

METHOD

In this study three sets of flight-worthy ANVIS with prototype high-resolution tubes were evaluated. One set had P22 phosphors in both tubes (P22), the second had P43 phosphors in both tubes (P43), and the third had a P22 in the right and a P43 in the left tube (mixed). Physical evaluation included measurement of ANVIS display luminance and chromaticity. Visual performance measures included visual acuity (VA), contrast sensitivity (CS), flicker detection and dynamic CS.

Stimuli for ANVIS were generated from an IBM-compatible computer and displayed on a super VGA video monitor. As described in previous studies (12–15), only the red gun of the monitor was used to limit stimulation to the spectral range of ANVIS. Stimulus contrast was calculated from photometric measurement of each software generated intensity step. Glass neutral density filters were placed before the objective lens of each system to introduce large changes in stimulus intensity corre-

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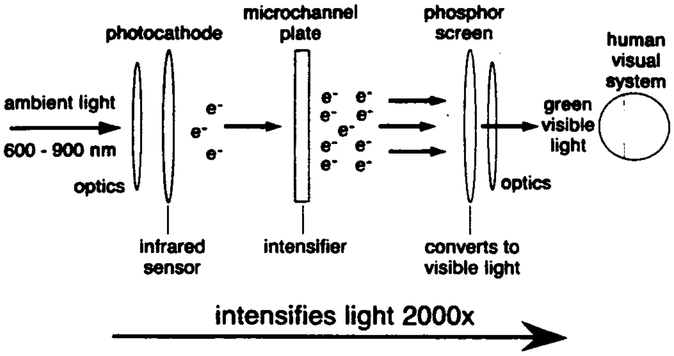

Fig. 1. Basic components of a night vision goggle.

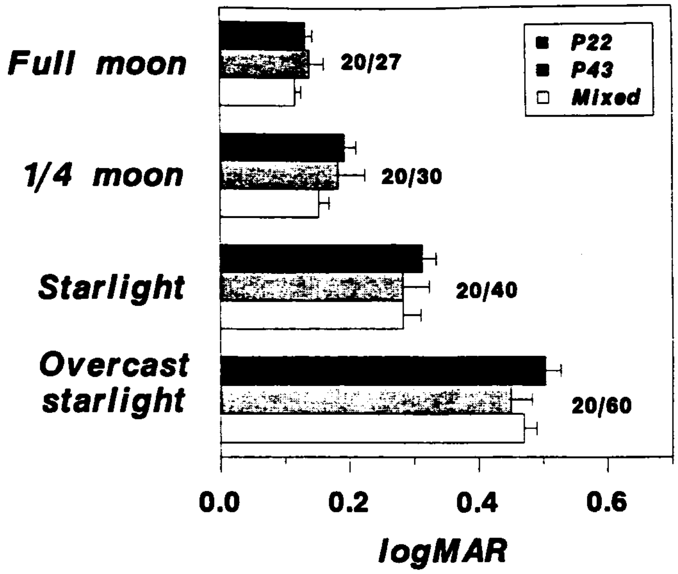

Fig. 3. Mean (±1 SE; n = 6 subjects) logMAR visual acuity is plotted for each system at each night sky.

sponding to different night sky illuminations. These simulated night conditions were defined operationally by measuring ANVIS display luminance across a range of stimulus intensity levels (Fig. 2). This yields a relation in which ANVIS display luminance increases linearly with input luminance up to the point at which the automatic brightness control operates (ABC point). Beyond this point, display luminance remains constant (at 1–2 fL) despite increases in ambient luminance provided that the ANVIS full field-of-view is illuminated uniformly (19). For the purpose of this study, full moon was defined as the intensity level 1 log unit above the ABC point, $\frac{1}{4}$ moon was at the ABC point, starlight 1 log unit below, and overcast starlight 2 log units below (Fig. 2). This enabled us to test across an extensive (3 log unit range) of stimulation to ANVIS.

All measures of visual performance were conducted binocularly since this is the normal configuration for flight. The ANVIS was mounted on an adjustable stand 2.4 m from the video display that subtended a visual angle of 4.5° × 5.9°, and provided the only source of illumination. Glass ND filters (3.9, 4.9, 5.9 and 6.9 log units attenuation) were placed in filter holders mounted directly in front of each ANVIS objective to attenuate the luminance of the video display, and simulate different night sky levels. VA, CS, flicker detection, and dynamic CS were assessed to compare performance between the three systems (P22, P43, and mixed). Subjects were tested with each system in a separate session (repeated measures design) with the order of systems counter balanced across subjects. VA and CS were measured with software generated letters displayed on the video monitor (11). On each trial five letters were presented centered on the display and the subject was asked to read the letters aloud and encouraged to guess if unsure. Size (VA) or contrast (CS) were decreased in 0.1 log unit steps per trial for a scoring precision of 0.02 log units per letter read correctly (1,16). VA letters were high contrast (93%) and varied in size from 0.1 logMAR (20/25) to 0.7 logMAR (20/100). CS was measured with letter sizes 0.2–0.3 log units larger than the high contrast VA threshold at each light level (0.4 logMAR or 20/50 for full and $\frac{1}{4}$ moon; 0.7 logMAR or 20/100 for starlight; 1.0 logMAR or 20/200 for overcast starlight). This made it possible to test along the steep, descending slope of the CS function where small changes in VA are associated with larger changes in CS (16). CS also was measured with the largest letter size (20/200) at all light levels to evaluate the change in contrast sensitivity with night sky condition. At each night sky condition, VA was measured first followed by CS. Night sky conditions were presented in ascending order (lowest intensity to highest) to discourage learning effects (since performance increases with light level), and to reduce the time required for light adaptation. Initial testing at the lowest light level was preceded by 10 min of adaptation to a uniform field.

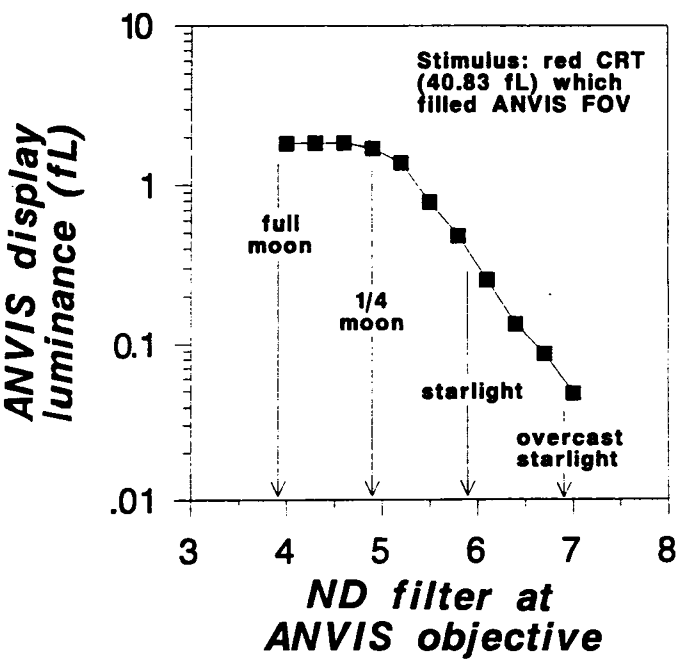

Fig. 2. Display luminance is plotted against log ND filter for a typical ANVIS. The stimulus was a color video monitor (red gun only; luminance = 40.83 fL) which filled the ANVIS field-of-view (FOV). Full moon, $\frac{1}{4}$ moon, starlight and overcast starlight were simulated with 3.9, 4.9, 5.9 and 6.9 log filters, respectively, placed in front of the ANVIS objective.

Flicker detection was measured with a 4 × 2 array of 8 patches of horizontal square wave grating. Spatial frequency was 6 cycles per degree, which is near the peak performance for human contrast sensitivity (6).

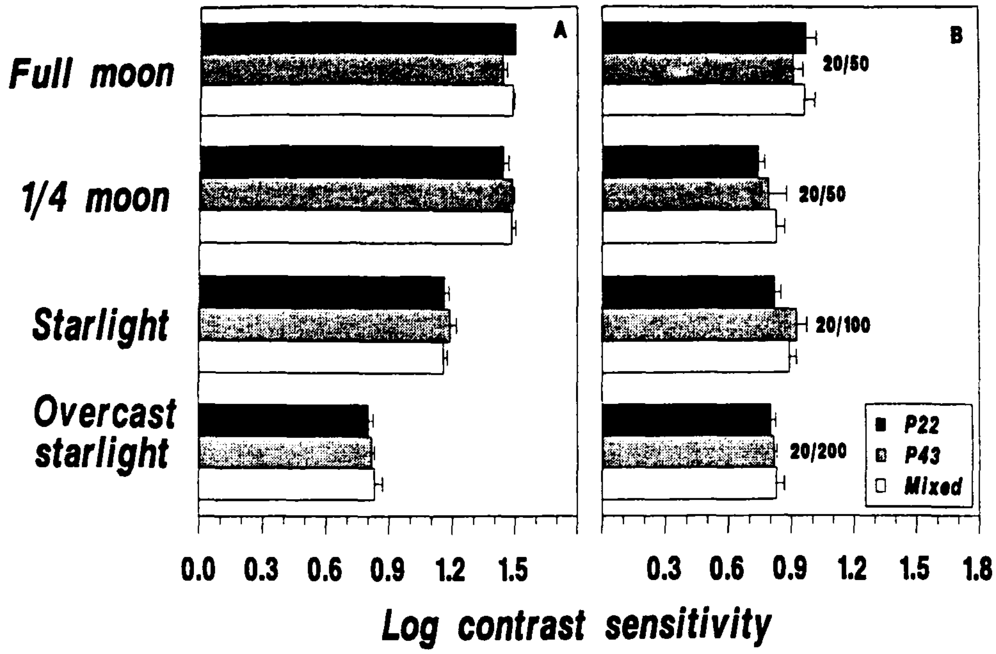

Fig. 4. Mean (±1 SE; n = 6 subjects) log contrast sensitivity is plotted for each system at each night sky. The left panel (4a) shows large letter CS (20/200), while the right panel (4b) shows results for smaller letter sizes which are indicated for each night sky.

Each grating patch was numbered (1–8) and differed in contrast by approximately 0.1 log unit steps (1-highest contrast; 8-lowest contrast). On each trial, the array of gratings was square-wave flickered at a different flicker frequency with values ranging from 0.5–16 Hz in 2× steps. The subject's task was to report the highest number grating (i.e., lowest contrast) at which flicker could be detected. Subjects also were instructed to use half-steps if they felt their threshold was between two numbered steps. Flicker frequencies were presented in random order and repeated three times at each frequency. The mean of the three values was computed as flicker detection threshold for each frequency. Display intensity for these measures simulated $\frac{1}{4}$ moon illumination.

Dynamic contrast sensitivity was measured with a forced choice, letter recognition task. Display intensity simulated quarter moon illumination and letter size was 20/100 (6 cycles per degree; same as in flicker experiment). On each trial a single letter appeared at a fixed location 0.7° left of center and moved 1.4° left to right at a velocity of $7° \cdot s^{-1}$. Each 200 ms trial was followed by a 1 s inter-trial interval (uniform field), and then the next moving letter appeared, and so forth, until a total of 15 letters were presented. During each 15-letter run, contrast was decreased in 0.1 log steps after 5 successive letters. The 15-letter run was repeated, and credit was given for each letter read correctly across 2 runs (0.01 log unit per letter).

There were 6 subjects (age 24–32) recruited from laboratory personnel who volunteered their participation in this study. All subjects had normal ocular health and binocular vision with corrected visual acuities of at least 20/20 in each eye. The subjects wore their refractive correction during testing, and were instructed on proper focus adjustments. All subjects gave their informed consent after protocol approval by institutional review committees.

RESULTS

Fig. 3 shows mean (±1 SE; n = 6 subjects) logMAR VA for each system (P22, P43 and mixed phosphors) plotted for each simulated night sky condition (increasing logMAR values indicate decreasing VA). Two-way analysis of variance (ANOVA) with measures repeated across system and night sky showed a significant main effect of night sky on VA ($F_{3,15} = 366.46$, $p < 0.0001$), as reported in previous studies (7,18,22). However, there was no effect of phosphor system on VA ($F_{2,10} = 1.26$, $p > 0.30$) and no significant interaction between system and night sky ($F_{6,30} = 1.04$, $p > 0.40$). Thus, regardless of night sky level, there was no significant difference between static VA's of each ANVIS system.

A similar effect was obtained with CS. **Fig. 4a** shows mean (±1 SE; n = 6 subjects) log CS (20/200 letter size) for each system (P22, P43 and mixed) plotted for each night sky (increasing CS indicates better performance). Two-way ANOVA with measures repeated across system and night sky showed a significant effect of night sky on CS ($F_{3,15} = 948.02$, $p < 0.0001$), as in previous studies (12,24). However, there was no effect of phosphor system on CS ($F_{2,10} = 0.25$, $p > 0.70$) and no significant interaction between system and night sky ($F_{6,30} = 2.22$, $p > 0.06$). Fig. 4b shows results for letter sizes on the descending slope of the CS function where small changes in VA are associated with larger changes in CS, and differences between systems would be exaggerated. However, even with this approach, there was no difference between phosphor systems ($F_{2,10} = 0.93$, $p > 0.40$) reaffirming our finding that static visual performance is the same with each system.

Fig. 5 shows mean (±1 SE; n = 6 subjects) log CS for flicker detection plotted against flicker frequency for each phosphor system. Two-way ANOVA with measures repeated across phosphor and flicker frequency showed a significant effect of frequency ($F_{5,25} = 51.55$, $p < 0.0001$) exemplified by the reduction in sensitivity at higher frequencies, and as shown in previous research (6,14). While there was a tendency for sensitivity to be slightly higher with the mixed phosphor system ($F_{2,10} = 4.50$, $p < 0.05$), there was no interaction between phosphor and frequency ($F_{10,50} = 0.93$, $p > 0.40$), and post

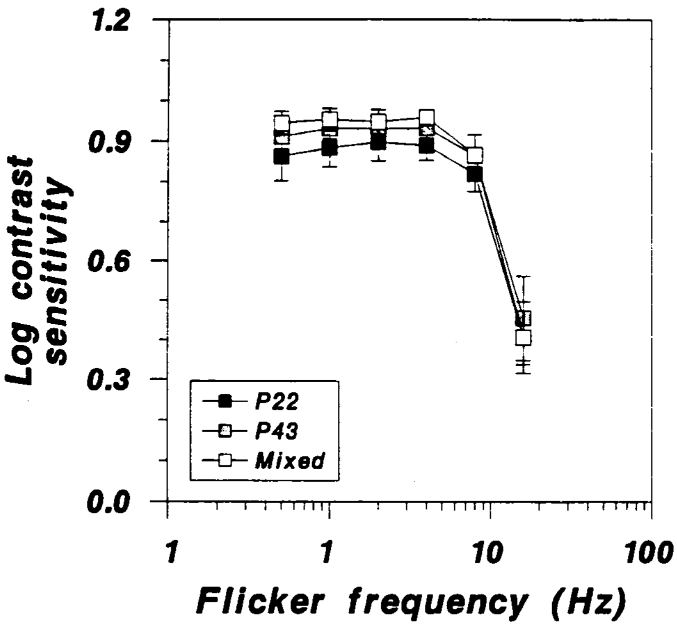

Fig. 5. Mean (±1 SE; n = 6 subjects) log contrast sensitivity to detect flicker is plotted against flicker frequency for each system.

hoc analysis revealed no significant differences between systems at each frequency (Tukey HSD test).

Fig. 6 shows mean (±1 SE; n = 6 subjects) log CS for recognition of a moving letter (20/100 letter moving at $7° \cdot s^{-1}$) plotted for each phosphor system. There was a small but significant difference between systems ($F_{2,10}$ = 5.91, $p > 0.05$). The difference between P22 and P43 systems was significant ($p = 0.023$), but the difference between mixed and P43 only approached significance ($p = 0.058$), and the difference between P22 and mixed systems was not significant ($p = 0.840$). It is emphasized that the magnitude of this effect is small and may not be operationally significant.

DISCUSSION

This study revealed no significant difference between visual performance of P22, P43 and mixed phosphor displays in ANVIS. Visual resolution, measured with VA

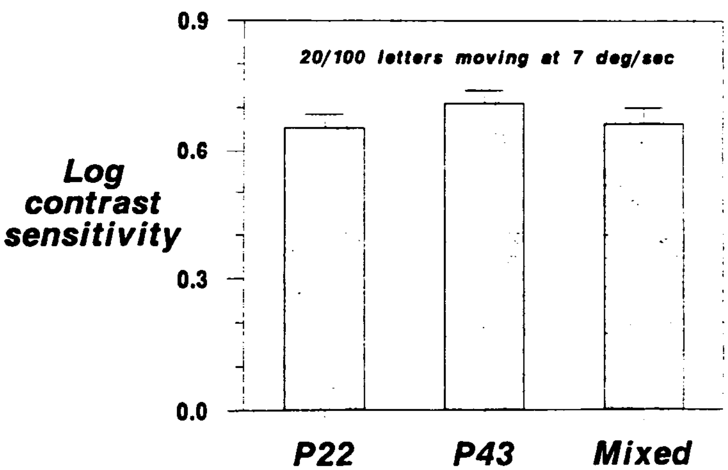

Fig. 6. Mean (±1 SE; n = 6 subjects) log contrast sensitivity to recognize a 20/100 letter moving at $7° \cdot s^{-1}$.

and small letter CS, showed no difference between systems. The same result was obtained with CS for large letters which tests sensitivity to moderate and low spatial frequencies. Dynamic visual performance, evaluated with flicker detection and CS for moving targets, also was about the same with P22, P43 and mixed systems. While the slight enhancement in dynamic CS with the P43 may relate to the faster decay time of this phosphor, this effect was quite small.

These findings indicate no obvious contraindications for using the P43 phosphor in ANVIS. This is not surprising since the luminances of P43 and P22 displays were comparable, and color differences were fairly subtle. Although we tested young adults, it is possible that older observers may perform slightly better with the P43 since absorption of short wavelength light by the human lens increases with age. The P43, which is yellow-green and contains less energy at shorter wavelengths than the P22, may be a more effective stimulus for the aging eye. On the other hand, focusing ability can be reduced in monochromatic light (2,4), and there is recent evidence that dynamic focusing ability is decreased in narrow band light comparable to a P43 phosphor (8). Chromatic aberration of the eye produces color fringes in broadband light that are thought to provide a stimulus for focusing, but these fringes are less apparent in narrow band light. While our laboratory findings revealed no evidence to suggest focus impairments, we did not include tasks requiring frequent changes in focus for which narrow band light may be less effective. However, when these NVG systems were tested in flight, pilots reported no difficulty alternating their visual focus between the P43 ANVIS display, which was optically focused for distance, and targets in the cockpit at near.

A more surprising result of this study was that subjects were able to tolerate the mixed system (P22 and P43) which had left and right displays of slightly different color. The left display was yellowish green (P43) while the right was deeper green (P22). Although this color difference was quite obvious when the displays were viewed alternately with each eye, under binocular viewing conditions none of the subjects noted that the displays appeared different in color, and performance was not significantly different with the mixed system. While these laboratory results and flight testing have yet to reveal obvious problems with the mixed system, a prudent approach would be to minimize mixing of phosphors in the same NVG. It is difficult to predict whether between-eye differences, such as that produced by mixing phosphors, would be as readily tolerated in the stress of a combat environment.

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